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Closing remarks at 4th NuFact ’02 Workshop, London, England, 6 July 2002

Andrew M Sessler

Center for Beam Physics, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA

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Abstract

A brief survey is given of actual R&D activities around the world. Following that, various conceptual developments significant to factories are reviewed. Then we turn to the costs of a factory. We discuss the present budgetary woes throughout the world and end with some closing remarks.

1. Introduction

In this paper we review, very briefly, the actual neutrino factory R&D activities going on about the world. We do not do this in detail, but to ‘trigger memory’ while giving emphasis to what I consider the most important activities. Subsequently, we cover some of the new ideas, then the costs of a neutrino factory, followed by budgetary woes and, finally, some closing, closing remarks.

Much R&D activity is going on and, surprisingly, this despite decreased funding and severe restrictions on the extent of activity. The R&D activity can, conveniently, be broken down by that in the US, Europe, Japan, and that done on an explicitly international basis. Of course, the picture is slightly blurred as there is good cooperation between all the regions, but various activities are directed towards possible projects in these three regions and that provides a convenient basis of separation.

2. R&D activities in the United States

Much was accomplished in the past few years:

- first round of target tests completed (C rod, Hg jet)
- first rf cavity tested (reached 24 MV/m)
- completed study II (6× performance increase, 25% cost reduction)
- began pressure tests on absorber windows
- began 201 MHz SCRF cavity design.

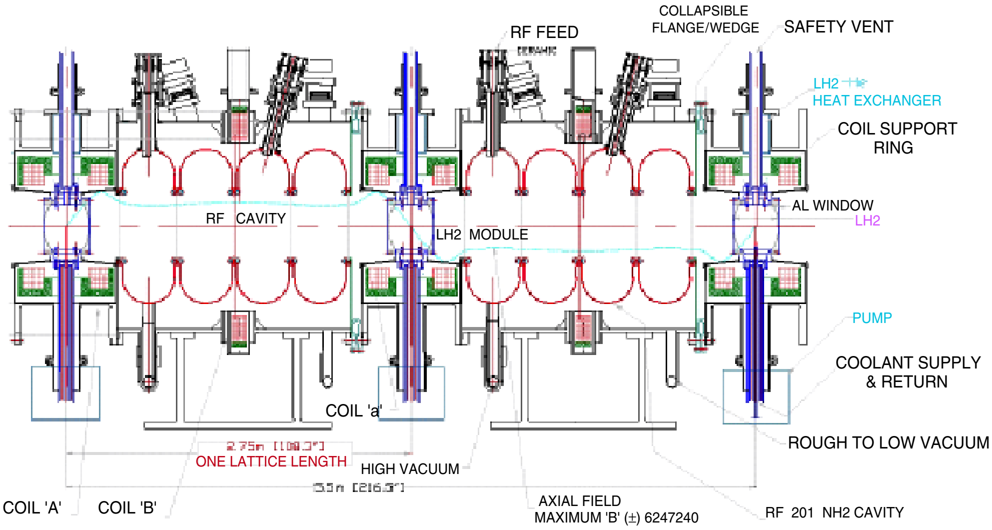

Figure 1. Two sections of the cooling channel of study II.

The cooling channel design of study II is shown in figure 1. One can see the detail of engineering design all of which was necessary so as to make reasonably accurate cost estimates. The target work validated the use of carbon with a 1 MW driver and the results on a mercury jet were encouraging, but require much more work (at higher beam intensity and with a magnetic field also present). The rf cavity work is important to the study of dark currents, while the design of room temperature 200 MHz is underway and the fabrication of superconducting 200 MHz (associated cryogenic and bake-out facilities) cavity has been accomplished. Much work is also being done on absorbers.

In addition, there has been lots of detailed work, at Fermilab, on possible proton drivers.

3. R&D activities in Europe

There has been considerable simulation and theoretical activity. One most interesting development is the possible use of beta beams as a source of neutrinos. There also has been considerable effort on mercury jets as targets (with close cooperation with the US) and very interesting work employing high magnetic fields at Grenoble. There has also been activity on an 88 MHz cavity.

In addition, the Europeans have a very active collaboration with the US on rf cavity design (they, in fact, built the first superconducting 200 MHz cavity) and are very involved in the muon scattering experiment, MuScat, see figure 2, occurring at TRIUMF.

Also, the British group has been active in the design of a proton driver for a neutrino factory. A possible scheme is shown in figure 3.

4. R&D activities in Japan

The neutrino factory scenario of the Japanese involves the use of FFAG accelerators and no cooling. The scenario is shown in figure 4. The FFAGs have a large momentum acceptance

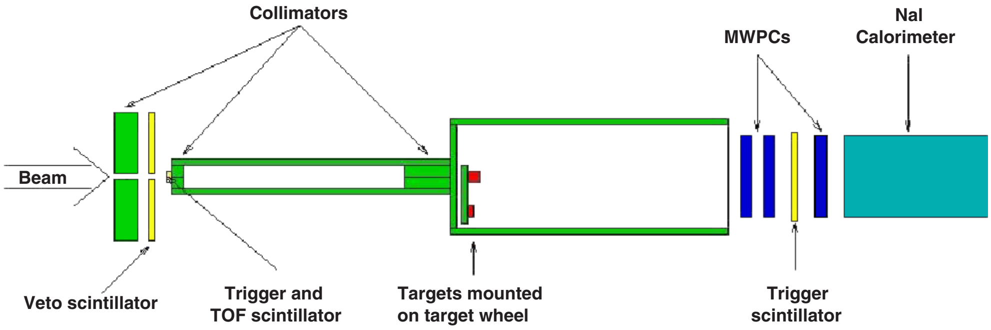

Figure 2. The MuScat experiment.

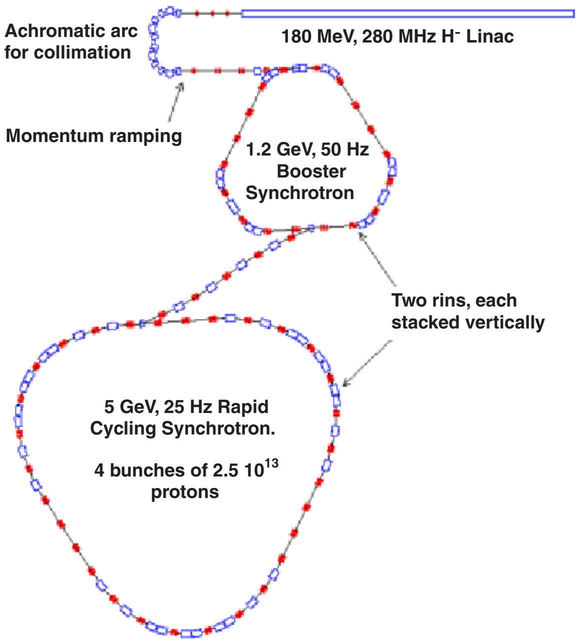

Figure 3. RAL accelerator studies of a 5 GeV, 50 Hz, proton driver for a neutrino factory.

and a large transverse aperture and thus allow a neutrino factory without the longitudinal phase space manipulation and the transverse cooling of other designs. Studies have included:

(i) determination of the optimum initial beam energy
(ii) study of the target and beam channel
(iii) study of injection and extraction
(iv) study of the dynamic aperture in both scaling and non-scaling FFAGs
(v) study of possible cooling in an FFAG.

In addition, the Japanese have a very active collaboration with the US on absorber design and construction.

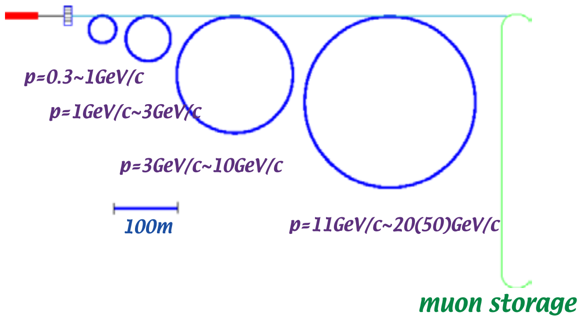

Figure 4. The Japanese FFAG option for a neutrino factory.

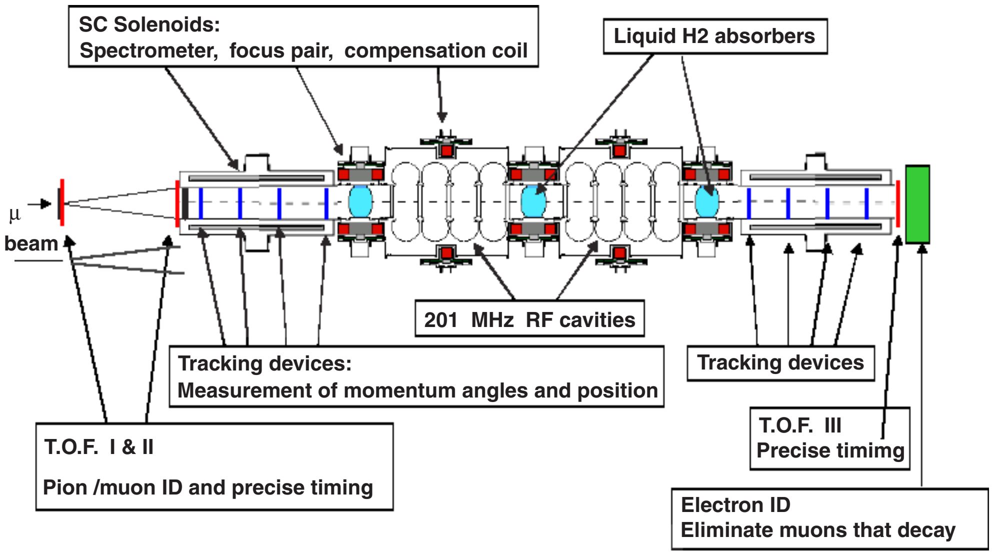

Figure 5. The International cooling experiment (MICE) as presently envisioned.

5. International R&D activities

The international effort is devoted to demonstrating cooling. Such an experiment would be too costly for any one region and, furthermore, it is not felt that the world needs more than one demonstration of cooling. The presently proposed experiment, most likely to take place at RAL in England, is shown in figure 5. The progress—technical, administrative, and political—in only a year is most impressive indeed; it has required considerable effort especially in Europe and the US.

6. Conceptual developments

There is very active work, throughout the world, under the general category of 'conceptual developments'. This work is motivated by the urge to develop a scenario for a muon collider (such a scenario having actual parameters for each component and simulation to show that it achieves the desired performance does not presently exist), and develop better ways to build a neutrino factory (less cumbersome, engineeringly simpler, more reliable, less costly).

Possible options for a neutrino factory, beyond study II, might be:

(i) achieve what we have assumed (high rf gradients, thin foils, target, etc)
(ii) increased driver power (in study II 1 MW to (say) 4 MW)
(iii) RF phase rotation (rather than induction units)
(iv) eliminate cooling
(v) spiral emittance exchange
(vi) use of FFAG for initial capture
(vii) use of FFAG for acceleration
(viii) lower acceptance RLA (consequence of improved cooling)
(ix) lower acceptance fast cycling synchrotron (possible with improved cooling)
(x) cooling rings.

There has been, and continues to be, a great deal of work done on all these ten topics. Details are presented in many papers in these proceedings. We can expect much more work in the years ahead with, presumably elimination of some ideas but considerable advance in others and, eventually, their incorporation into a base design ('study III') which, hopefully, will be less expensive than the factory of study II.

7. Neutrino factory costs

'Costs' is a delicate subject especially as it involves many 'touchy' subjects such as the reaction of the community and the reaction of the funding agencies. Let me be bold, however, and present some of my thoughts. (Allowed in a 'Closing Remark' paper.)

The best cost estimate we have is that from study II: 1.7 B$, but it is really 1.9 B$ (from the added 10% for items not included). This is an unloaded number. When loaded (escalation, EDIA, contingency, overhead) it becomes slightly more than twice that or 4.0 B$.

How can we cut the cost? Of course, we can improve the design and, surely, our present R&D is aimed in just that direction—but, on top of that, the simplest way is to stage as we have described, first at NuFact 01 and then in considerable detail at Snowmass 01. With staging each step is 'modest':

(i) proton driver and target facility (super beams) 250–330 M$ (1 MW) or 330–410 M$ (4 MW)
(ii) phase space manipulation (muon physics) 660–840 M$
(iii) linac (low-energy neutrino work) 220–250 M$
(iv) recirculator and storage ring (full factory) 550 M$ (20 GeV) or 1250–1350 M$ (50 GeV)
(v) muon collider (no cost estimate exists).

These costs, for various stages, are unloaded costs; real costs are twice as much (and, of course, staging is more expensive than simply 'going ahead full steam').

What are the prospects for cost reductions, whether or not one stage?

(i) rf bunching: might save 100 to 200 M$
(ii) Initially one could have no transverse cooling (either reduce performance or increase the driver power and come out about the same): might save 200 M$
(iii) FFAG or fast cycling boosters for acceleration: might save 100 M$
(iv) Cooling rings: might save 100 M$

Table 1. DOE funding for muons (FY03 is based on DOE guidance).

Year	DOE-base ($M)	DOE-MC ($M)	Total ($M)
FY99	2.8	2.2	5.0
FY00	3.3	4.7	8.0
FY01	3.0	3.2	6.2
FY02	3.0	2.8	5.8
FY03	2.1	1.4	3.5

Put this all together (and it is not obvious that one can) and one would save 600 M$. The total cost of a neutrino factory would be 1.3 B$, which, when loaded, becomes 2.6 B$. We can see that, as presently envisioned, a neutrino factory is *not* in the 1 B$ class; most likely the cost is more than 3 B$.

8. Budgetary woes

There are very strict restrictions on neutrino activities at CERN as (an understandable) consequence of bringing the LHC on line despite severe budgetary problems. Similarly, there is minimal activity in Japan as a consequence of focusing upon the joint project. And, in the United States, we have experienced a sharp decline in support of muon activities.

Let me be more explicit about the US problems (if for no better reason than I have experienced them directly (and painfully)). During the last few years we have experienced a significant decrease in the DOE funding for muons as is shown in table 1.
Looking forward to the next fiscal year FY03 (starting on 1 Oct. 2002), we hope to:

- begin target-solenoid fabrication
- continue beam tests at AGS
- continue Be window development and launch grid development
- continue dark current studies
- begin fabrication of high-power 201-MHz NCRF cavity and test solenoid
- begin LH_2 absorber tests (requires completing MTA)
- develop formal proposal for MICE (international effort)
- study alternative design approaches (e.g., Japanese FFAG scheme).

The proposed FY03 budget will *not* allow most of this to proceed, to say nothing of eliminating AGS HEP operation.

9. Closing, closing remarks

Perhaps, in closing, it is natural to think: What did I learn at this conference? What is new in the field? Let me suggest, in my closing, how those questions might be answered:

(i) The particle physics motivation is very strong and, in fact, getting stronger with each passing day.
(ii) There is need for super beams, but they cannot do everything; we need a factory also.
(iii) Much progress is being made on hardware.
(iv) The international cooling experiment, MICE, has greatly advanced and it is only its first year.

(v) There has been good progress on proton drivers (necessary for both super beams and factories).

(vi) Significant new ideas and/or progress:

- (a) Cooling rings (They work!)
- (b) RF bunching (May eliminate the need for induction accelerator)
- (c) FFAG (non-scaling and nonlinear) (May be good for capture and/or acceleration)
- (d) Fast-cycling synchrotron (May simplify acceleration)
- (e) Beta-beams (May have a useful role).

(vii) These new ideas suggest the possibility of cost reduction of a neutrino factory and, even, the possibility of achieving a muon collider.

We are experiencing serious budget problems in the USA, severe constraints at CERN, and unrelenting pressures on the manpower (to do necessary things for the joint project) in Japan. But the particle physics motivations are overwhelming and the possibility of experimental realization (both the detector and the factory itself) is, at this point, substantive. Furthermore, we are a dedicated group. We shall not 'go away' for we feel, strongly, that we are doing the right thing in developing this science.

Finally then, simply keep at it. We are doing great things, making fine progress. Sooner or later—and lets hope it is 'sooner' rather than 'later'—the HEP community will come around.

Our many thanks go to the organizers of NuFact 02. And I hope to see you next year at NuFACT 03 in the USA, at Columbia University, 5–11 June 2003.